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Mechanical Fasteners for 1800°F and Above

by

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INTRODUCTION

This presentation is intended to review the state-of-the-art of mechanical fasteners for 1800°F and above and to discuss some of the problems associated with the use of these fasteners.

Until recently the need for mechanical fasteners at 1800°F and above appeared urgent in view of the projected requirements of the space shuttle for metallic heat shields which would be reusable for 100 cycles of orbit and reentry. The present concept of the thermal protection system however has resulted in a deemphasis of the metallic systems and an emphasis on the reusable external insulation (REI) approach and on the ablative approach used so successfully on the Mercury, Gemini, and Apollo programs. Each of these approaches may require a compromise of the original goal of 100 reuses and quick turnaround. Work is therefore continuing on the metallic concept as a back-up system or possibly as the system which will ultimately permit the achievement of the original program guidelines.

MATERIALS UNDER CONSIDERATION

An all metallic space shuttle orbiter might well employ the following spectrum of materials:

Aluminum Alloys	↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓	Increasing Temperature
Alloy Steels		
Titanium Alloys		
A-286		
Inco 718		
Rene' 41		
Haynes Alloy No. 188		
TD NiCr		
Coated Refractory Alloys (Cb752-C129Y)		

Up through the Rene' 41 the fastener technology is fairly well established and this discussion will therefore deal with only those alloys with a 1800°F or higher capability which will include HA188, TD NiCr and the refractory metal alloys such as Cb752 and C129Y.

HAYNES ALLOY NO. 188 (H.A. 188)

This alloy is a compromise between the high temperature strength of Haynes Alloy No. 25 and the oxidation resistance of Hastelloy "X". It possesses good fabricability and is an excellent fastener material in that the base metal properties are readily attainable in a finished fastener. Many different fastener configurations have been made in HA188 for heat shield development programs, primarily under Phase B funding. Included were flush head, pan head, hex head, and special head bolts in sizes primarily #10 (3/16") and 1/4". Also made were plate nuts, flanged and unflanged hex nuts and rivets.

TD NiCr (Ni - 20 Cr - 2 ThO₂)

This material is the second of the usable high temperature dispersion strengthened materials to come into prominence. (The first being TD Ni.) The high temperature strength is dependent upon the presence of an ultra-fine dispersion of ThO₂ particles throughout the Ni - 20 Cr matrix. At present the only source of material suitable for fastener manufacture is Fansteel Inc.

The properties of TD NiCr fasteners are sufficiently high at 2200°F to permit their consideration for use up to this temperature. A graph of 100 hour rupture stress for various temperatures is shown in Figure 1. This includes other materials for a comparison.

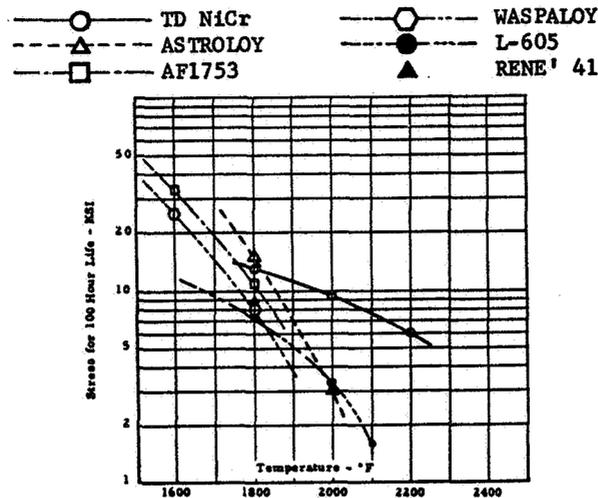


Figure 1. Effect of Temperature on Stress to Produce Rupture in 100 Hours.

These properties are not attainable in parts in which significant amounts of deformation are applied to generate a head. Herein lies the main obstacle in the path of the use of TD NiCr fasteners. The strength of the TD NiCr is so dependent on prior work and thermal history that the result of various amounts of work in the forming of most types of heads is to render the fastener head-critical with the failure strength usually being significantly less than optimum material properties or thread strength. This problem is the subject of work soon to be completed by Standard Pressed Steel Co.'s R & D Laboratories under Air Force Contract F-33615-67-C-1494. A typical microstructure of a forged head part is shown in Figure 2. In this figure three distinct structures can be seen with failure usually occurring through Zone 2.

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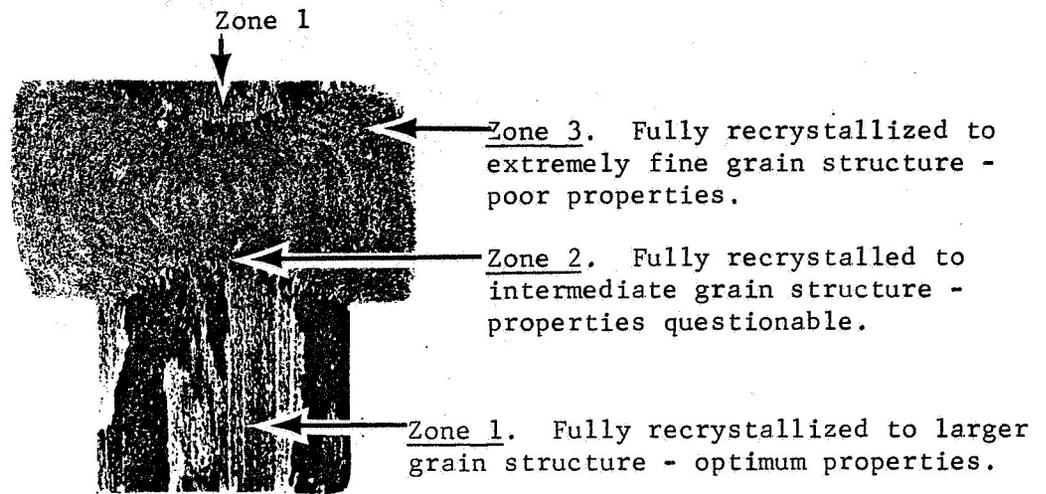


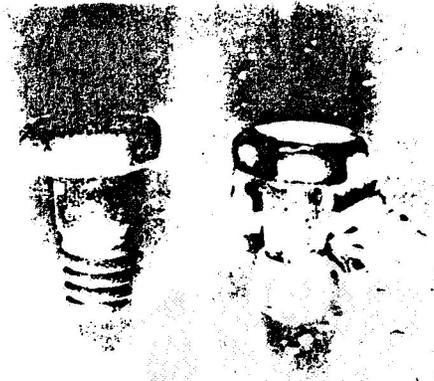
Figure 2. TD NiCr bolt head sectioned to show structure. Material was initially unrecrystallized, head forged at 2000°F, recrystallized at 2450°F.

REFRACTORY METAL ALLOYS

Beyond the temperature limit of TD NiCr it becomes apparent that the useful engineering materials must be those with melting temperatures significantly above those of nickel and cobalt base alloys. Thus the logical choices are columbium (melting point 4474°F) and tantalum (melting point 5425°F). The two other most common refractory metals, molybdenum and tungsten are not generally considered because of their low ductility and resulting poor fabricability.

The main problem associated with these materials is their poor oxidation resistance which makes a coating mandatory in an oxidizing environment.

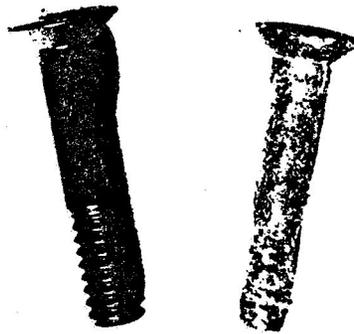
Examples of this need are shown in Figures 3, 4, and 5. Figures 3 and 4 show the drastic difference between coated and uncoated columbium and tantalum bolts. Note that both uncoated parts were exposed to only 1500°F for one hour whereas the coated parts were exposed near their maximum use temperatures. Figure 5 demonstrates that the coating process is at least as important as the coating chemistry. In this example the bolt in the rear of the test block is T-222 coated with WSi_2 by Process "A". The oxide on the front edge of the block is the residue of three T-222 bolts coated with WSi_2 by Process "B". These examples clearly indicate the need not only for a coating but also indicate the need for careful process selection, process control and quality assurance procedures to prevent catastrophic oxidation failures.



Coated-Sylvania R512E
Exposed 2400°F
32 One Hour Cycles

Uncoated
Exposed 1500°F
1 Hour

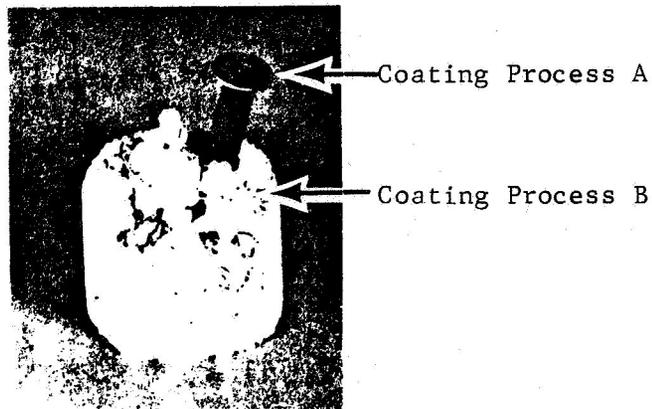
Figure 3. Cb752 bolts exposed as shown.



Coated Vitro WS12
Exposed 3000°F -
10 minutes

Uncoated
Exposed 1500°F -
1 Hour

Figure 4. T-222 bolts exposed as shown.



WS12 Coated
Exposed 3000°F - 10 minutes

Figure 5. T-222 bolts exposed as shown.

Beyond the coating problem, the properties of columbium and tantalum appear attractive enough to permit their use at 2500°F and 3000°F respectively.

In the case of columbium alloy fasteners, many have been made for Shuttle Phase B programs. These have all been made by hot forging heads, rolling threads and all other operations typical of a high performance aerospace fastener. The dimensions were adjusted to allow for coating.

EFFECT OF COATING ON USABILITY

It is logical to ask why, since good coatings are available, are these problems associated with the use of mechanical fasteners. The problems relating primarily to fasteners can be summarized as follows:

A. Difficulty in Coating Internal and External Threads

The presence of such things as sharp radii on various parts of fasteners creates difficulties for the coaters. It is extremely difficult to achieve a uniform coating over such abrupt changes in geometry. The accessibility of the threads in small diameter nuts makes coating application difficult and inspection virtually impossible.

Once the coating has been applied these same areas become those most subject to coating damage due to chipping during handling and use.

One partial remedy to this problem is the use of the thread form developed by SPS under Air Force Flight Dynamics Laboratory sponsorship. This thread form provides for closely controlled roots and crests with liberal radii. It can be adjusted for individual coatings over the range of thickness common to these materials. This Refractory Thread Form is shown in Figure 6.

B. Close Tolerances in Threads

As a corollary to "A", the normal tolerances on screw threads are significantly smaller than the differences which can be created by normal coating variation. In considering this one must keep in mind the fact that a .0001" variation in coating thickness effects the pitch diameter by $4 \times .0001$ " or .0004". This is illustrated in Figure 7.

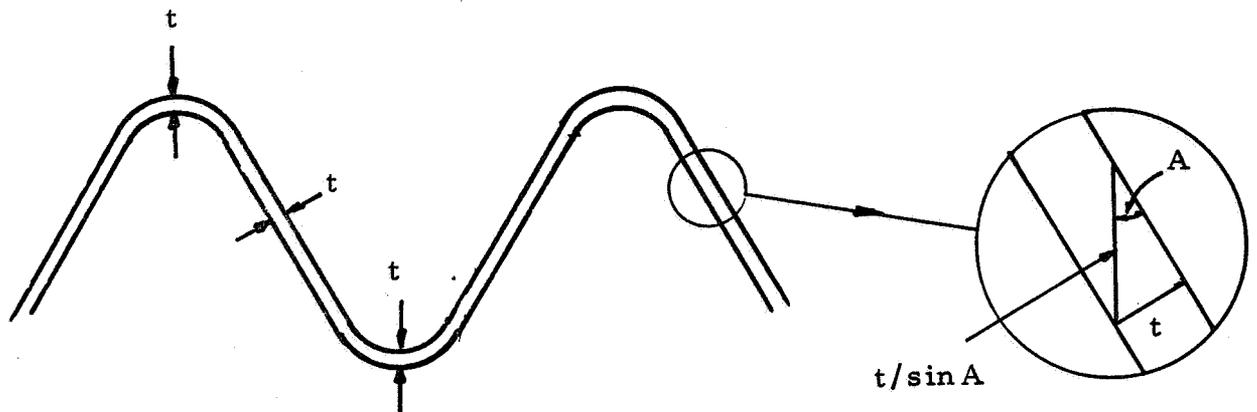


Figure 7. Factors involved in coating thickness allowance determinations.

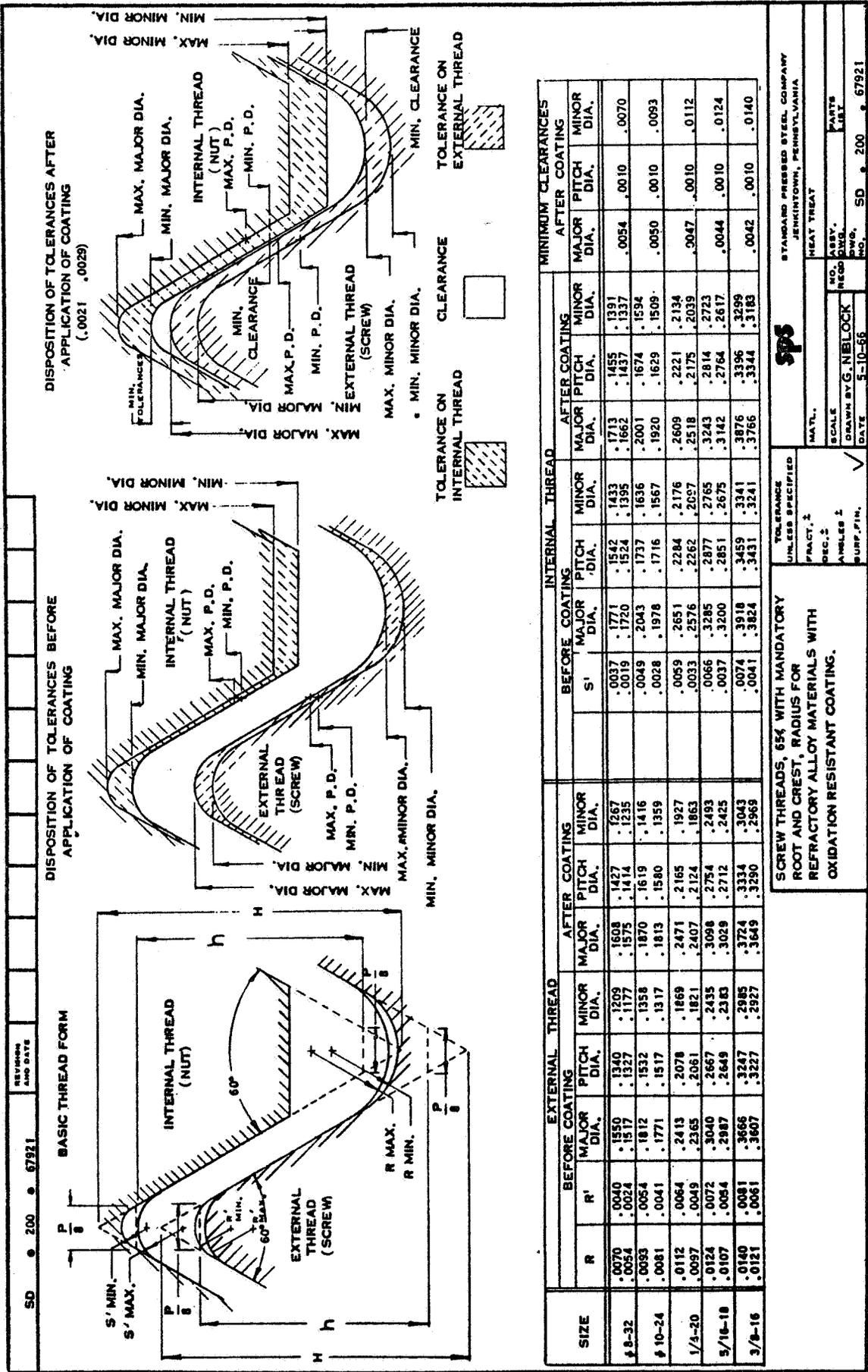


Figure 6.

7300 A
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SD 200 67921

REVISIONS AND DATE

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

HEAT TREAT

NO. ABBY.
SCALE BY G. NIBLOCK
REGD. DWG.
DATE 5-10-56

PARTS LIST

SD 200 67921

UNLESS SPECIFIED

FRACT. 2

SEC. 2

ANGLE 1

SURF. FIN. ✓

SCREW THREADS, 65% WITH MANDATORY ROOT AND CREST, RADIUS FOR REFRACTORY ALLOY MATERIALS WITH OXIDATION RESISTANT COATING.

Since the thread form has an angle A of 30°, $t/\sin A = 2T$, which is the effect on the pitch radius. This, of course, becomes 4T when considering the pitch diameter. Add to this the fact that both internal threads and external threads experience this 4T factor and it would be possible with a .0005" coating tolerance to cause a .004" variation in finished dimensions. In the small fasteners typically used thus far the .002 pitch diameter variation is approximately equal to the tolerance allowed on the pitch diameter uncoated parts. This could severely limit the interchangeability which is desirable in high volume fastener usage.

C. Need for Mechanical Drives for Tightening

If a fastener is to perform its function of holding a joint together under a defined preload, it must have this preload applied to it by some means. The normal way is to provide a driving configuration in the head so that the bolt can be torqued relative to the nut (or tapped hole). The presence of a drive of some sort creates another area of difficult coatability. In addition, and probably more important, the torque applied to tighten the fastener can cause chipping of sharp corners and in areas of high localized stresses.

The best available solution to this problem is to design drives which provide only the necessary torque and minimize the sharp corners and localized bearing areas.

D. Abrasion and Compression in Threads and Bearing Areas

Because of the fairly rough nature of the coatings (50 Mi-AA) installation causes somewhat higher torques than desired and this can cause the coating to chip. In addition the high local stresses in the contact areas of the threads and on the bearing areas under head and under nuts can and does cause compressive failure of the coatings.

E. Locking Features

A requirement for locking features in a bolt or nut creates a problem by further localizing stresses in the area of the locking feature.

F. "Welding" of Coated Components

The conditions existing in the use of coated refractory alloy fasteners creates the ideal diffusion bond that is:

1. High compressive stresses
2. High temperature
3. Semi-fluid coating components (SiO₂)

Difficulties are often encountered in disassembly and even when fasteners can be removed it is common to create coating damage during removal. One answer is the use of a barrier to prevent a bond from forming. One such barrier was developed by SPS. It is a proprietary formulation known as LF87-66-1. This provides lubrication for one installation and a barrier

for ease of removal. The residue is easily removed after one thermal cycle so that a fresh application can be made for the next thermal cycle. This material has a temperature use range up to 2600°F and is, therefore, also useful in the prevention of seizing on HA188, TD NiCr and other high temperature materials.

SUMMARY

I have attempted herein to discuss this area of technology with emphasis on some of the problems which need to be solved before a metallic heat shield can become a reliable item of hardware. I must point out that with the present reduced interest in this field the work necessary to solve the problems will not be pursued. Only active interest by N.A.S.A. or the Shuttle Contractor will generate the activity necessary to bring the technology of mechanical fasteners for 1800°F and above to the level it must be to fulfill the needs of a major program such as the Space Shuttle.

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